# Japanese Aerospace Literature This month: *Metal Matrix Materials*

**A93-55425 Age hardening behavior of SiC whisker reinforced Al-Li-Cu alloy composites.** SUNG-KIL HONG, HIROYASU TEZUKA, and AKIHIKO KAMIO, *Japan Institute of Light Metals Journal* (ISSN 0451-5994), Vol. 43, No. 6, June 1993, pp. 328–334. 18 Refs.

The age hardening behavior of SiC(w)/Al-2.3 mass pct Li-2.8 mass pct Cu alloy composites fabricated by the squeeze casting method was investigated using micro Vickers hardness, calorimetric technique, and TEM observation. The composites showed remarkable age hardening, and the age hardening of the composites was more accelerated with increasing SiC whisker volume fraction. The composites aged at 423 K showed a hardness increase of two stages, while the unreinforced matrix alloy showed a monotonous hardness increase. It was clarified that the first stage of hardness increase of the composites was due to the precipitation of the delta (Al3Li) phase, and the second one was mainly due to the precipitation of the T(1) (Al2CuLi) phase. In composites, the T(1) phase precipitates became dominant with increasing SiC whisker volume fraction and controlled the age-hardening rate at 423 K, because the T(1) (Al2CuLi) phase precipitated preferentially on dislocations generated during quenching after the solution treatment due to the difference in the thermal expansion coefficient between the SiC whisker and matrix.

**A93-53787 Fracture analysis of whisker-reinforced aluminum alloys.** MASANORI KIKUCHI, MAMTIMIN GENI, and KAZUMI HIRANO, *Japan Society of Mechanical Engineers, Transactions A* (ISSN 0387-5008), Vol. 59, No. 560, April 1993, pp. 1017–1023. 13 Refs.

The fracture process of whisker-reinforced aluminum alloys is studied. First, tensile tests are carried out on specimens of various orientations. Dimple fracture occurs at the edge of the whisker fiber due to the stress concentration. It is also found that delamination occurs at the whisker matrix interface in the T-specimen. Then the fracture process is simulated by FEM. For the constitutive equation, Gurson's yield function is used. Void volume fraction is used as a fracture parameter and a conventional fracture analysis is carried out. Numerical results qualitatively agree with those of experiments. The delamination effect between the base metal and the whisker fiber is considered. It is concluded that the effect of the delamination is very small before fracture of the specimen.

**A93-52592 Characterization and microstructural modifications of a pressure die cast eutectic aluminium-silicon alloy-graphite composite.** B. K. PRASAD, T. K. DAN, and P. K. ROHATGI, *JIM, Materials Transactions* (ISSN 0916-1821), Vol. 34, No. 5, May 1993, pp. 474–480. 26 Refs.

The paper describes the preparation of pressure die cast (PDC) Al-Si composite (BS LM13) alloy containing dispersion of graphite particles and an investigation of the effects of the applying pressure (505 KPa) and heat treatment (516 C for 3-8 h and ageing at 180 C for the same duration) on its matrix microstructure and its hardness, density, and electrical resistivity. A comparison with the gravity die cast (GDC) composite showed that the matrix microstructure of PDC composite was considerably refined over the one processed by GDC technique, although the morphology of the microstructural constituents remained unchanged. The variation on hardness, density, and electrical resistivity of the PDC composite was quite less than for the GDC composites. Heat treatment of the PDC composite brought about significant and useful morphological changes at the cost of insignificant loss in properties.

**A93-52588 Use of mullite whiskers for aluminium matrix composites.** THAN T. LONG, TOSHIRO AIGA, HIROMI HANAMITSU, MIKIYA FUJII, HIROYUKI FUJIMORI, and KATSUHIRO YAMAMOTO, *JIM, Materials Transactions* (ISSN 0916-1821), Vol. 34, No. 4, April 1993, pp. 364–372. 18 Refs.

A process for the synthesis of mullite whiskers by firing a mixture of kaolinite, aluminum fluorite, and graphite is obtained. The mullite whiskers have barlike form with average width ranging from 0.05 to 3 microns and aspect ratio of about 20. The reinforcement with mullite whiskers results in drastic improvement in wear resistance of aluminum alloy and less attack against the counter material in comparison with silicon carbide whiskers or alumina fibers. The elastic modulus of the composite increases to a value nearly comparable to that reinforced with silicon carbide whiskers. The secondary dendrite arm spacings of aluminum alloy in the composite prepared by liquid metal infiltration technique are about half of those in the monolithic alloy. The secondary phases of aluminum alloy tend to form at the whisker surfaces due to the rejection of solute elements to last solidifying regions. No damage of whiskers that can be interpreted due to the chemical reactivity with solute elements and alpha-Al is detected.

**A92-48252 Preparation of three-dimensionally isotropic SiC-aluminum composites and their mechanical properties.** YUJI YAMAMOTO, HAJIME IZAWA, SHOJIRO OCHIAI, and KOZO OSAMURA, *Japan Institute of Light Metals Journal* (ISSN 0451-5994), Vol. 42, No. 5, May 1992, pp. 293–298. 12 Refs.

SiC-aluminum composites were prepared by a liquid phase hot-pressing technique on the basis of a porous silicon carbide body which forms a 3D network structure. Each of silicon carbide and aluminum composites forms a 3D network structure intermingling with each other.

**A93-53045 Evaluation of thermally induced stress in alumina fiber reinforced Al-5 percent Cu alloy by X-ray diffraction.** YASUKAZU IKEUCHI, TAKAO HANABUSA, and HARUO FUJIWARA, *Japan Society of Materials Science Journal* (ISSN 0514-5163), Vol. 42, No. 477, June 1993, pp. 606–612. 28 Refs.

The stress generated as a result of the difference in coefficient of thermal expansion between matrix and fiber was measured during the heating and cooling processes of a gamma-alumina fiber-reinforced Al-5 percent Cu alloy. An automated device was used for in situ X-ray diffraction measurements at elevated temperatures. The composite with 50 vol pct of 17 micron-diameter fibers was fabricated by a squeeze casting method, and was given an aging heat treatment which consisted of heating the composite to 800 K for 4 hr, water quenching, and reheating to 463 K for 6 hr. At room temperature (RT), the matrix of the water-quenched composite showed a tensile thermal residual stress of 80 MPa. In situ measurements on the composite heated up to 463 K showed a constant matrix compressive stress of -50 MPa during the whole aging period of 6 hr. In the subsequent thermal cycling process of the aged composite, the matrix stress changed elastically between -50 MPa at 463 K and 100 MPa at RT. On heating back to RT after cooling the composite to RT from 463 K and then to liquid nitrogen temperature, a reduction of the residual stress was observed. On further heating of the composite from RT, plastic deformation of the matrix was observed.

**A93-51128 Creep of advanced metal matrix composite SiC(CVD)/Ti-15-3.** NOBUTADA OHNO, KENJI TOYODA, NAOKI OKAMOTO, TAKUSHI MIYAKE, and SHIGETO NISHIDE, *Japan Society of Mechanical Engineers, Transactions A* (ISSN 0387-5008), Vol. 59, No. 557, Jan. 1993, pp. 105–110. 9 Refs.

Creep tests of an advanced continuous fiber-reinforced metal matrix composite SiC(CVD)/Ti-15-3 were performed for three fiber directions: 0 deg, 45 deg, and 90 deg at 450 C. Specimens were chucked inside a furnace to realize a uniform temperature field in the gage section, and elongation in creep is measured. We find the following: (1) creep deformation and rupture can occur even in longitudinal creep at a stress level much lower than the tensile strength, although the SiC(CVD) fiber itself does not creep at all; (2) this creep behavior is explained partly if we consider the stress relaxation in the matrix material during longitudinal creep tests of the composite; and (3) off-axis creep of 45 deg has some ductility, which is greater under lower stress.

**N94-10858 Tribological characteristics of hot-pressed self-lubricating composites (Hottopuresu hou de sakuseishita jiko junkatsusei fukugou zairyou no toraiboroji tokusei ni kansuru kenkyuu).** MINEO SUZUKI and MAKOTO NISHIMURA, National Aerospace Lab., Tokyo. Space Technology Research Group. 51P. (NAL-TR-1160; JTN-93-80444; DE93-793623).

Tribological characteristics of hot-pressed self-lubricating composites were investigated to develop new high performance tribo-materials for space applications. The composites consisted of molybdenum disulfide (MoS2), refractory metal oxide (MoO3, MoO2, WO3, WO2, Ta2O5, or Nb2O5), and refractory metal (Mo, W, Ta, or Nb). Friction tests were performed in a vacuum, in nitrogen, and in air atmospheres using ring-on-disk type friction testers. The best material composition under the applied test conditions (contact pressures of from 0.5 to 4 MPa and sliding speeds of from 0.11 to 0.55 m/sec) was found to be composition of MoS2 80 percent plus MoO2 10 percent plus Nb 10 percent. In a vacuum, this composite showed a coefficient of friction of less than 0.07 and a specific wear rate of less than 10(exp -11) cu mm/(N x mm). Good tribological performance was also obtained with composition of MoS2 80 percent plus Nb2O5 10 percent plus Nb 10 percent, MoS2 80 percent plus MoO2 10 percent plus Mo 10 percent and MoS2 80 percent plus MoO2 20 percent. For the composites showing good tribological performance, a thin, uniform transfer film was formed on the steel ring surface. X-ray diffraction results showed that Mo2S3 was present in almost all the composites, thereby, suggesting that MoS2 partially dissociated into Mo2S3 during the hot-press process. It was also found that the addition of the refractory metal oxide and/or metal promoted both the dissociation of MoS2 and the chemical reaction among the involved species.

**A93-22536 Age-hardening behavior of 6061 aluminum alloy reinforced with SiC whiskers.** HIROYUKI TODA, TOSHIRO KOBAYASHI, and MITSUO NIINOMI, *Japan Institute of Metals Journal* (ISSN 0021-4876), Vol. 56, No. 11, Nov. 1992, pp. 1303–1311. 28 Refs.

The age-hardening behavior of the 6061 aluminum alloy, with and without SiC whisker reinforcement, was investigated experimentally using hardness measurements, calorimetry, and transmission electron microscopy. The objective of the study was to determine the effect of the reinforcement on the aging response of the cast 6061 aluminum matrix. It is found that the addition of SiC whiskers does not alter the overall age-hardening sequence. The reinforcement, however, is found to affect the precipitation kinetics of the matrix. Times to achieve peak hardness are shortened over the entire temperature range investigated. The accelerating effect of the reinforcement is particularly pronounced at low aging temperatures.

**A93-45275 Development of tungsten fiber reinforced superalloys.** *Ishikawajima-Harima Engineering Review* (ISSN 0578-7904), Vol. 33, No. 1, Jan. 1993, pp. 7–12. 6 Refs.

Tungsten fiber reinforced superalloys (TFRS) consisting of long, parallel tungsten fibers with 0.3 mm diameter have been developed. The key technologies are a diffusion barrier coating on the surface of the tungsten fibers and the new fabrication process. The diffusion barrier coating using the ion-plating technique improves fiber/matrix compatibility and prevents the interaction between the fibers and matrix during the fabrication process and/or in service. A new fabrication process termed the Bandage Method wraps the tungsten fibers carefully with thin, cleaned matrix alloy strip, and was used to manufacture the test specimens and the model blades. This study was carried out in collaboration with Volvo Flygmotor AB and IHI.

**A93-42325 Temperature-dependence of tensile strength of Si-Ti-C-O fiber-reinforced aluminum matrix composite.** KENJI MATSUNAGA, SHOJIRO OCHIAI, KOZO OSAMURA, YOSHIHARU WAKU, and TAKEMI YAMAMURA, *Japan Institute of Light Metals Journal* (ISSN 0451-5994), Vol. 43, No. 4, April 1993, pp. 219–224. 12 Refs.

An investigation is conducted of the tensile strength of unidirectional Si-Ti-C-O fiber-reinforced Al produced by squeeze casting in the room temperature-773 K range. Attention is given to longitudinal and transverse strength, matrix shear modulus, and fiber stress concentration for various temperatures.

**A93-42324 Application of powder liquid forging technique to fabrication of Al2O3 or SiC particle/6061 aluminum alloy metal matrix composites and their mechanical properties.** YO TOMOTA, TAKAHISA OHNUKI, MING HUANG, YUJI ICHINOSE, HIROMICHI OHTA, and YO TAKEUCHI, *Japan Institute of Light Metals Journal* (ISSN 0451-5994), Vol. 43, No. 4, April 1993, pp. 213–218. 9 Refs.

The powder-liquid forging (PLF) technique presently used to consolidate SiC- or Al2O3-particle reinforced 6061 Al alloy MMCs yields components with up to 30 percent reinforcement through pressing of the powder compact above the melting point. It is established that the Young's modulus and hardness of solution-treated MMCs linearly increase with solution treatment; age-hardening is especially effective in the case of the Al2O3-reinforced MMC due to the formation of MgAl2O4 through Mg loss from the matrix during PLF.

**A93-42322 Machinability of SiC particle reinforced aluminum alloy composite material.** BIING-HWA YAN and CHRA-CHUNG WANG, *Japan Institute of Light Metals Journal* (ISSN 0451-5994), Vol. 43, No. 4, April 1993, pp. 187–192. 5 Refs.

Al alloy matrix composites are associated with tool wear during machining. In this work, the turning test for SiC particle-reinforced Al alloy composite materials was performed, and the effects of SiC particle size and content on the tool wear and surface roughness were discussed. The tool wear increased with increasing SiC particle size and content. Only a diamond tool cut the SiC particle reinforced aluminum alloy composite material without difficulty. In the case of a carbide tool, the cutting condition should be low speed as well as high feed rate. Removing chips during cutting was effective in decreasing tool wear. In the wet cutting, however, this resulted in increased tool wear. While the increasing SiC particle size resulted in the greater surface roughness, increasing SiC content improved surface roughness.

**A93-40449 Strengthening of metal matrix composite by shape memory effect.** YOKO YAMADA, MINORU TAYA, and RYUZO WATANABE, *JIM, Materials Transactions* (ISSN 0916-1821), Vol. 34, No. 3, March 1993, pp. 254–260. 14 Refs.

The strengthening of an MMC by the shape memory effect of dispersed TiNi particles was theoretically studied. An analytical model was constructed for the prediction of Young's modulus, yield stress, and work-hardening rate on the bases of Eshelby's (1957) equivalent inclusion method. The analysis was performed on the TiNi particle/Al metal matrix composites with varying volume fractions and prestrains of the particle. The present analysis has shown that the above parameters increase with increasing the volume fraction of the particles, and the yield stress increases with increasing prestrain while Young's modulus and the work-hardening rate are independent of prestrain. The residual stress caused by the shape memory of predeformed fillers has been predicted to contribute significantly to the strengthening of this composite. This approach has an advantage of definite control of residual stresses compared to the stress controlled by the mismatch of the thermal expansion coefficients between the matrix and filler. The magnitude and the direction of residual stresses can be controlled by prestraining the composites with dispersed particles.

**A92-47378 Interface reactions between CVD-SiC fibers and molten Al-Ti, Al-Zr alloys.** TADASHI ARIGA, YASUO MIYAMOTO, and KATSUMASA HOSOI, *Japan Institute of Light Metals Journal* (ISSN 0451-5994), Vol. 42, No. 4, April 1992, pp. 198–204. 5 Refs.

Interface reactions between CVD-SiC fibers and liquid aluminum containing Ti or Zr were investigated in the temperature range 973-1273 K. The reaction time ranged from 0.9 to 7.2 ks. The additional elements Ti and Zr were selected because they are active in aluminum. The addition of Ti or Zr accelerated the interface reaction between fibers and the molten matrix. Ti was more effective than Zr to accelerate the interface reaction.

**A93-40447 Enhanced mechanical properties of TiNi shape memory fiber/Al matrix composite.** YASUBUMI FURUYA, ATSUSHI SASAKI, and MINORU TAYA, *JIM, Materials Transactions* (ISSN 0916-1821), Vol. 34, No. 3, March 1993, pp. 224–227. 3 Refs.

A design concept of shape memory TiNi fiber reinforced/Al metal matrix composite (SM-MMC) was proposed. Mechanical tensile properties such as stiffness and yield strength, were improved by the strengthening mechanisms: back stress in the Al matrix induced by stiffness of TiNi fibers and the compressive stress in the matrix caused by shape memory shrinkage of TiNi fibers. Damping capacity of the composite was also increased. These results suggest that this composite with prestrain can be applicable and is suitable for machinery, especially engine components where the material becomes stronger at higher temperatures owing to the shape memory effect.

**A93-40423 Residual strength and its distribution of SiC/Al-alloy composites wires after cyclic loading.** H. FUKUNAGA, Y. LU, and J. HAMADA, *Japan Society for Composite Materials Journal* (ISSN 0385-2563), Vol. 19, No. 1, 1993, pp. 15–19. 15 Refs.

The practical application of fiber-reinforced metals to structural components requires investigation of the residual strength of the composites after cyclic loading. Tensile test of SiC/Al-alloy composite wires after cyclic loading were conducted, and the effect of number of cycles and stress amplitude on the residual strength and its distribution was examined. The residual strength decreased about 6 percent, and the scatter slightly increased at the initial loading cycle; these two values then remained constant up to about 100 cycles, with the stress amplitude of 80 percent of the tensile strength. When the stress amplitude increased, the residual strength decreased and the scatter increased. Applying the proof test to the composites, it was found that the proof testing stress did not always guarantee the proof stress of the composites. A method to revise the proof stress is proposed by using the experimental data of the residual strength, taking into account the test-induced reduction in strength.

**A93-40044 Ultrasonic non-destructive evaluation of elastic constants and fractional ratio of Al2O3 fiber of aluminum base composites.** YOUNG C. PARK, GYU C. LEE, TSUYOSHI MIHARA, and KAZUHIRO DATE, *Japan Institute of Metals Journal* (ISSN 0021-4876), Vol. 57, No. 3, March 1993, pp. 301–306. 11 Refs.

The purpose of this study was to develop a nondestructive material evaluation method of aluminum alloy base metal matrix composites (MMCs) by ultrasonics. Five aluminum base MMC specimens in which the fractional ratios of fiber varied from 0 percent to 31 percent were fabricated. The relationships between the acoustic properties, microstructural features, and elastic constant were compared. The ultrasonic velocity method was useful for nondestructive elastic constant measurement of composite materials, since this method had the same measurement accuracy as the conventional strain measurement method. Furthermore, the velocity and attenuation parameter are also related to the fractional ratio of fiber and these relations may be utilized for the ultrasonic nondestructive evaluation of fiber structure in MMCs.

**A93-34607 Age hardening behavior of Al-Li alloy composites reinforced with SiC whisker fabricated by squeeze casting.** SUNG-KIL HONG, HIROYASU TEZUKA, and AKIHIKO KAMIO, *Japan Institute of Light Metals Journal* (ISSN 0451-5994), Vol. 43, No. 2, Feb. 1993, pp. 82–88. 17 Refs.

The age hardening behavior of SiC whisker-reinforced Al-Li alloy prepared by squeeze casting has been investigated using Vickers micro hardness test, calorimetric technique, and TEM observation. It was found that the Li concentration in the composites decreased slightly when the Al-Li melt was infiltrated into the SiC(w) preform. The age hardening sequence of SiC(w)/Al-Li alloy composites was essentially same as that of Al-Li matrix alloy. But the age hardening behavior of the composites was more accelerated with increasing the SiC(w) volume fraction at 373 K, 423 K and 473 K than that of the unreinforced matrix alloy. It was considered that the dislocation density increased with increasing SiC(w) volume fraction because dislocations were generated due to differential thermal contraction of the matrix/SiC(w) during quenching after the solution treatment. Furthermore, it is made clear that the remarkable age hardening effect in SiC(w)/Al-Li composites was obtained by precipitation of very fine and high density of second phase delta-prime(Al3Li) in the matrix of composites.

**A93-20896 Cavitation erosion of SiC-whisker-reinforced aluminum composite.** JING-YU LI, TSUNENORI OKADA, and YOSHIRO IWAI, *Japan Society of Mechanical Engineers, Transactions A* (ISSN 0387-5008), Vol. 58, June 1992, pp. 909–915. 6 Refs.

Cavitation erosion of a SiC-whisker-reinforced aluminum composite was studied by vibratory erosion tests in ion-exchanged water, and SEM observations of the eroded surfaces and erosion particles were made. The composite showed fairly good erosion resistance. The composite made by a high-pressure infiltration process is superior to that by a powder metallurgy process. The erosion resistance of the former showed a good correlation with the ratio of the square of the Brinell hardness to the elastic modulus. The composite in which the volume fraction of the whiskers is more than 30 percent showed almost the same resistance as high carbon and stainless steels. The behaviors occurred because the whiskers prevent the plastic deformation of the matrix metal and the growth of eroded cracks, resulting in a decrease in the size of erosion particles.